

## **Integration of a Miniaturized Conductivity Sensor into an Animal-Borne Instrument**

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### **LONG-TERM GOALS**

Habitat changes affecting marine mammals can range from small scale cyclic changes (e.g. tides) and natural physical processes (e.g. fronts and eddies) to changes on an ecological scale that range from years to decades and from tens to thousands of kilometers. These habitat changes can be natural or anthropogenic (e.g. pollution, sound). For example, short-term changes of the physical environment can cause changes in marine mammal populations by affecting pup survival, while long-term unidirectional changes can result in permanent habitat change or even habitat loss that may have a significant impact on entire populations. Population consequences of the foraging behavior of marine mammals depend on the availability of prey, which in turn is in part driven by the way animals react to the quality and dynamics of their immediate environment at the scale they are able to sample it. Predicting how marine mammal populations respond to habitat changes is also essential for developing conservation management strategies. To investigate such links, we need the appropriate environmental information at the relevant scales and, while large scale monitoring of environmental change can be accomplished cost-effectively by approaches such as remote sensing, getting fine scale information from the marine mammal's immediate environment requires local in-situ monitoring.

The availability of information about the marine environment has rapidly improved over the last two decades. The Global Ocean Observing System (GOOS) is now providing a range of observations measured from space, ships, moored instruments, free floating buoys and profilers to accurately describe the present state of the oceans. Compared to twenty years ago, this relative abundance of data is providing a global view of the ocean system that can support operational ocean services worldwide. However, it is still struggling to provide data at the appropriate scales to link oceanographic observations to animal movements, especially in the high latitude seas and on the continental shelf. One rapidly developing approach has been information using the animals themselves to carry the required instruments to collect in-situ environmental data (e.g. Fedak 2013). Such data is necessarily at an appropriate scale to link changes in animal behavior to changes in their environment.

However, existing instruments capable of providing data at the necessary accuracy are limited in available attachment methodologies and the size of instruments can render other approaches difficult.

Animal-borne instruments delivering temperature and/or salinity measurements from remote regions are highly accurate, but sensor and data relay packages combined necessitate instruments too big to be carried by smaller animals. Reducing the size of the sensors would allow the instruments to be deployed on a much wider range of species, including other smaller ones. But it would also be advantageous in other important ways. It would make available space for more complex sensor packages and geolocation approaches. It would allow compatibility with other data relay modalities, mounting and attachment configurations or additional energy supplies while maintaining the current size and weight. Another known issue is that the only accurate conductivity sensor available for animal-borne instruments is based on an inductive cell, which is sensitive to the attachment method and orientation (Boehme et al. 2009) needing a 'rigid' attachment, which is normally only possible when the animal can be restrained during the attachment procedure limiting their use to seals and small cetaceans. The use of electrodes instead of an inductive cell to measure the conductivity of the water would limit the measured field immensely (Huang et al. 2011) and would enable conductivity measurements which are not influenced by the attachment method. Animal-borne CTD sensors based on electrodes would therefore be able to provide accurate measurements while e.g. fanning around a barb as used to tag large cetaceans, opening up a new field of ecosystem studies.

## **OBJECTIVES**

This project aims to be a stepping stone in developing an instrument enabling accurate measurements, while the instrument is rotating around a barb attachment as it is used to tag large cetaceans. Such methodology would provide for ecosystem studies of large cetaceans that are not currently feasible. The objective of this program is to design an instrument that can provide quality data from a non-rigid attachment (e.g. barb and wire) and to successfully demonstrate that this instrument can record long-term time series within the marine environment.

## **APPROACH**

The only existing marine mammal tag capable of recording and transmitting vertical temperature and salinity profiles from remote locations is the Conductivity, Temperature and Depth - Satellite Relay Data Logger (CTD-SRDL) designed and built by the Sea Mammal Research Unit Instrumentation Group (SMRU Instrumentation Group), St Andrews, UK. While this instrument works well when glued to the fur of pinnipeds, it showed to be sensitive to the attachment method and orientation (e.g. Boehme et al. 2009). Errors in the order of 0.10 in salinity can occur and are caused by disturbing the

external field of the inductive cell by the attachment. The use of electrodes instead of an inductive cell to measure the conductivity of the water would limit the size of the measured field (Huang et al. 2011) and would enable conductivity measurements which are not influenced by the attachment method. The University of Southampton together with the Sensors Development Group at the National Oceanographic Centre Southampton (NOCS), UK, developed a miniature conductivity and temperature sensor system (CT sensor) in recent years (Huang et al. 2011). This CT sensor consists of a multi electrode conductivity cell with a platinum resistor bridge to produce an integrated CT sensor and is combined with an impedance measurement circuit to support the sensors and to create a CT sensor system. Within this project, we want to adapt the hardware and software of this existing NOCS sensor package for easy integration into the SRDL design, so that the data can be relayed via telemetry and that the sensor is suitable for long term deployments on marine mammals.

Our approach was therefore as follows.

1. Modify an existing miniature conductivity-temperature (CT) sensor, which can deliver oceanographic information and incorporate this sensor into the proven design of a Satellite Relay Data Logger.
2. Test and evaluate the communication between CT sensor and a Satellite Relay Data Logger including logging of measurements for subsequent transmission using a telemetry system.
3. Laboratory tests and calibration of CT sensor data to demonstrate it can obtain data of sufficient quality to investigate the links between animal behavior and local physical conditions.
4. Test of the waterproofed instrument in the marine environment including long-term stability of measurements to demonstrate it can obtain data of sufficient quality to investigate the links between animal behavior and local physical conditions.
5. A design study for a behavioural and environmental tag to be deployed on large cetaceans.

## **WORK COMPLETED**

The project started in August 2013. One post-doctoral researcher was hired and started to work on this project. Two requirements were defined for the CT-sensor for integration into the existing SRDL concept. The first requirement was an interface system provided with the CT-sensor to create a CT-package that can exchange information with the SRDL. While the size of the CT-package was not a driving factor at this early stage, loose size restrictions had to be adhered to for it to be fitted at the side of the existing SRDL. It was also decided that the complete potted CT-package needed to fit initially into a cuboid with sides of 60 by 25 by 20mm. Communication and data logging were tested and evaluated after the CT package was modified and a common interface protocol established.

The interface for easy communication between the CT-package and SRDL was determined to be an I<sup>2</sup>C interface with a Serial Data Line (SDA) and a Serial Clock (SCL). In addition three more connections were deemed to be necessary: a connection for the supply voltage (Vbat) of 100mA peak current and a voltage between 3.4V and 3.7V; a common ground (GND) and an ENABLE connection, which can be used to power on or off the CT-sensor completely (0V=off, Vbat=on) to conserve energy. The communication between the SRDL and the CT-sensor is implementing three I<sup>2</sup>C slave commands.

- Read conductivity in low power, low resolution mode to determine if the instrument is in the water or not (WET-DRY mode)
- Read conductivity and temperature at high precision (near) simultaneously and filtered to match time-constants if necessary to avoid salinity artefacts. The resolution should be 16 bits distributed over the ranges of -10°C to 55°C for temperature (resolution 1mK) and 0-80mS/cm in conductivity (resolution 1.25  $\mu$ S/cm)
- Write command(s) to store calibration data.

This interface is simplifying the integration process into the existing SRDL system, but will also enable others to integrate the CT-package easily (Figure 1).



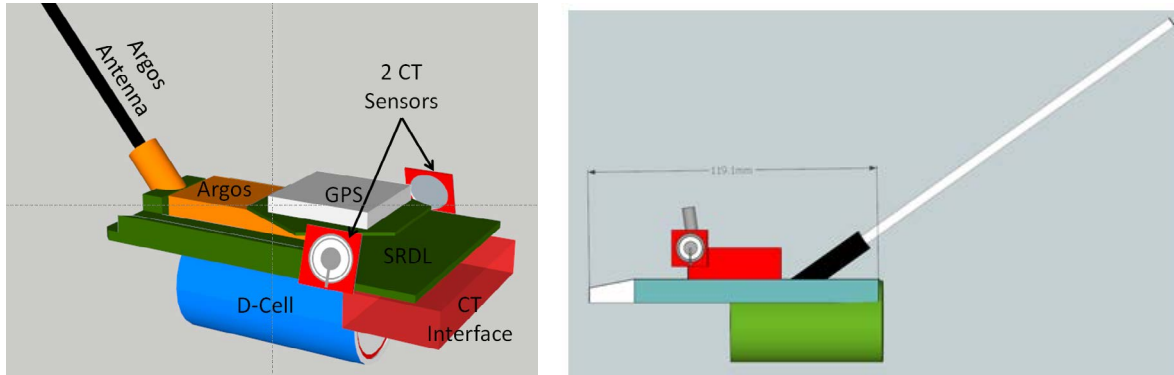
***Figure 1: Two CT sensors (left), a single CT sensor including interface board (middle) and a CT package integrated into a SRDL (right) are shown.***

After a common interface was found, the CT-package was interfaced with an SRDL instrument (Figure 1). Then, communication and logging of data was successfully tested in the lab by putting the whole package into an environmental chamber and changing the air temperature. We found a quadratic relationship between the temperature probe (Impedance of the PRT) and the air temperature over the full range (0-35°C). These results showed a temperature accuracy of better than 0.1°C over the full range. A linear effect of temperature on the conductivity sensors was found and described, so that the conductivity measurements can be compensated for temperature.

One CT-SRDL was then tested under laboratory conditions and calibrated against a Valeport miniCTD probe (SN#44968). Then the CT-SRDL was compared to readings from the Valeport miniCTD over a new set of measurements.

Another CT-SRDL unit was waterproofed for deployment in the marine environment and completely immersed in water. However, the communication between the CT package and the SRDL was not reliable and the instrument is currently still debugged.

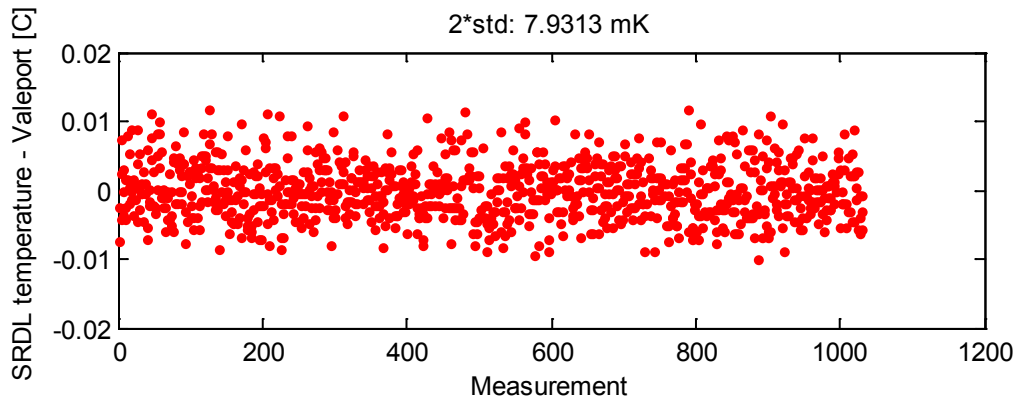
A design study to develop an instrument enabling accurate measurements from non-rigid attachments was done. To minimize drag the body of the tag will have a low drag shape and near neutral buoyancy in sea water. The center of gravity is placed in such a way that the electrode will be far enough ( $>2\text{cm}$ ) away from the body of the animal to deliver reliable conductivity measurements. The tag is also self-righting even when on the back of an animal when dry. This will keep the antenna away from the animal's body improving the chances to transmit data successfully (Figure 2). We hope to get funds in a future project to build this instrument.



**Figure 2:** Two design studies for electrode based CTD tags for non-rigid attachment. Instrument on the left has two CT sensors and a GPS receiver, while the right one has one CT sensor. The epoxy body is not shown.

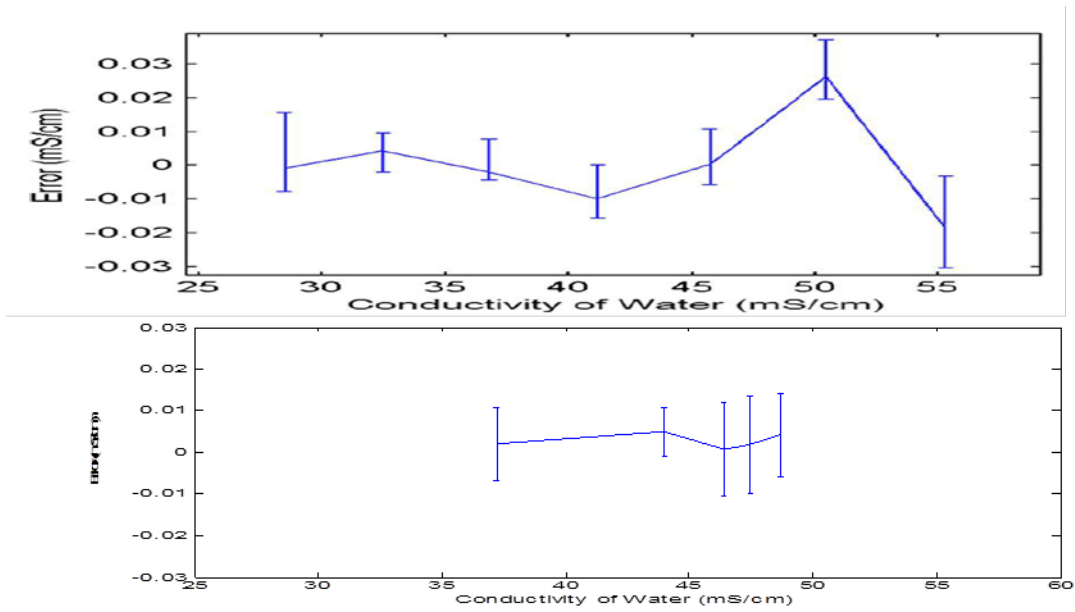
## RESULTS

After calibrating the CT-SRDL was compared over a range of temperatures ( $0\text{--}22^\circ\text{C}$ ) to the Valeport miniCTD and the measurements were on average closer than  $8\text{mK}$  (2 times standard deviation) (Figure 3).



**Figure 3:** Differences in temperature between the CT-SRDL and the reference probe (Valeport CTD) over a range of temperatures.

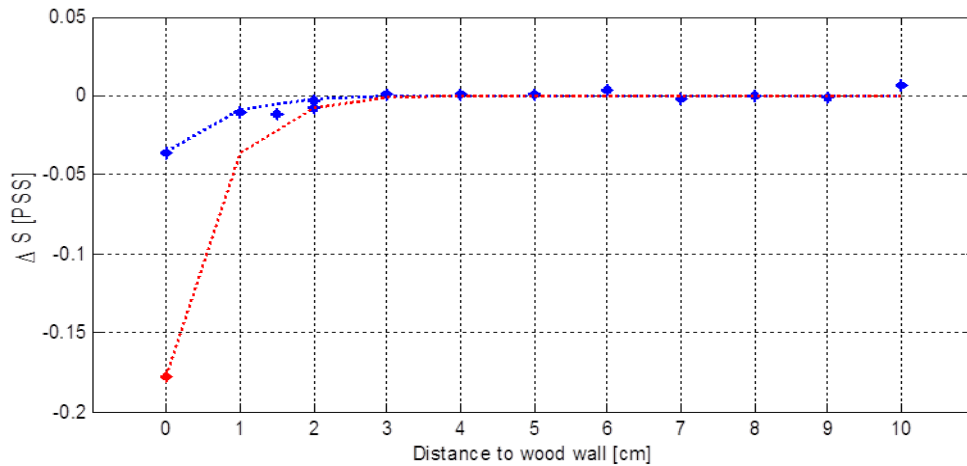
Conductivity measurements of the CT-SRDL were compared to the Valeport miniCTD as well. The electrode based sensor showed an accuracy of better than  $0.01\text{mS/cm}$ , which was expected from previous studies (Figure 4). This will make reliable conductivity (salinity) measurements from non-rigid attachments possible.



**Figure 4: Error in the measured conductivity for five conductivity points (bottom). Each point on the curve is the mean error, the bars show the maximum range of value for the 100 measurements at each conductivity point. Data from a previous study is shown on top (Huang et al 2011).**

The resulting error of the calculated salinity at typical values ( $T=10^{\circ}\text{C}$ ,  $C=38\text{mS/cm}$  and  $P=0\text{dbar}$ ) would then be better than 0.02, which are comparable to the accuracies provided by the existing CTD-SRDL (Boehme et al. 2009).

Another important aspect in using an electrode for conductivity measurements is to be able to reduce the external measured field. Following Boehme et al. (2009) we introduced a disturbance (wooden board) close to the sensor and measured the changes in conductivity readings relative to the distance between the disturbance and the sensor (Figure 4). An offset in the conductivity readings for the standard CTD-SRDL was measurable at distance of up to 10cm (Boehme et al. 2009), while the new electrode based CT-SRDL was only affected when the disturbance was closer than 2cm (Figure 5).



**Figure 5: Salinity offsets introduced by placing a wooden board close to the electrode of the CT package. Disturbance perpendicular to electrode in blue and parallel (frontal) in red.**

## **IMPACT/APPLICATIONS**

All tasks were completed and other research groups already registered interest in the final product to be used with rotating barb attachments to tag large cetaceans to support ecosystem studies of large cetaceans in the Arctic. Reducing the size of the CTD sensor would allow a smaller instrument to be deployed on a much wider range of species, including many other smaller ones. However, minimizing size would also be advantageous in other important ways. It would make available space on the instruments for more complex sensor packages and geo-location approaches (Figure 2 left). It would also allow compatibility with other data relay modalities, mounting and attachment configurations or additional energy supplies while maintaining the current size and weight.

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